General Training On Methodologies For Geological Disposal in North America

IAEA Network of Centers of Excellence

Highlights from a Worldwide Review of URL's and Nuclear Waste Disposal Development

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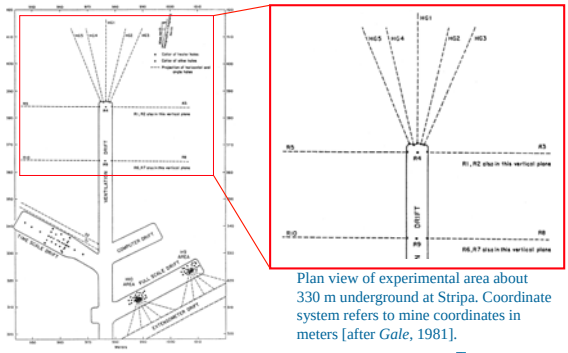
Increasing use of URLs

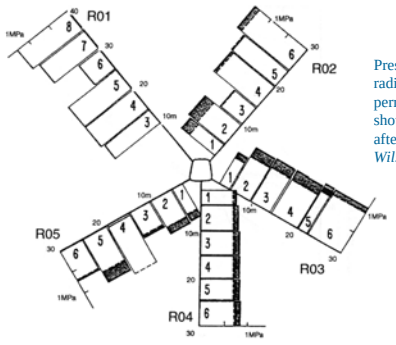
- 1977 Stripa URL project started in Sweden

Investigations At Stripa on Fracture Flow in Rocks



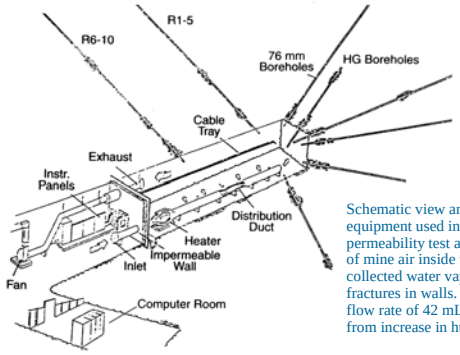
Plan view of experimental area about 330 m underground at Stripa. Coordinate system refers to mine coordinates in meters [after *Gale*, 1981].

Hydraulic Head Measurements in Radial Boreholes



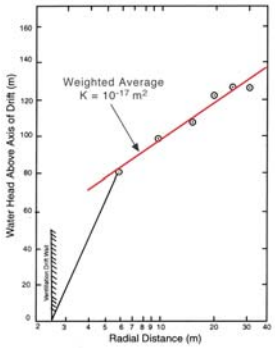
Pressure measurements in radial boreholes of large-scale permeability test. Stippled area shows pressure increase 8 days after packing off RO1 [after *Wilson et al*., 1981].

Large-Scale Permeability Test at Stripa



Schematic view and layout of equipment used in large-scale permeability test at Stripa. Circulation of mine air inside walled off room collected water vapor emanating from fractures in walls. Liquid equivalent flow rate of 42 mL/min determined from increase in humidity.

Distance-Drawdown Plot of Hydraulic Heads



Distance-drawdown plot for observed hydraulic heads with air temperature of 30º C. Steeper slope just outside drift wall due to excavation damage and two phase flow.

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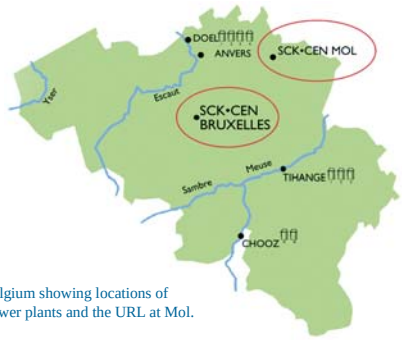
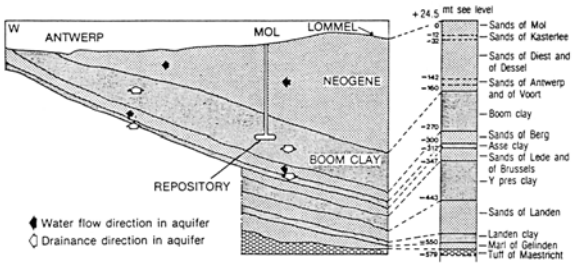
- 1980s Development of URL in Belgium

URL at Mol, Belgium



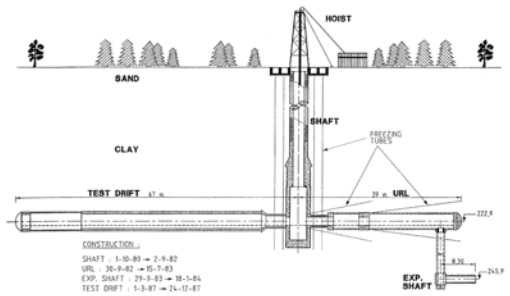
Map of Belgium showing locations of nuclear power plants and the URL at Mol.

Geologic Cross-section of Mol Site



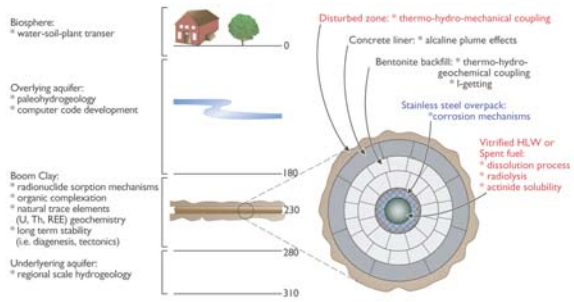
East-West geologic cross-section showing groundwater flow system and the 100-meter thick Boom Clay formation at the Mol site.

HADES URL at Mol



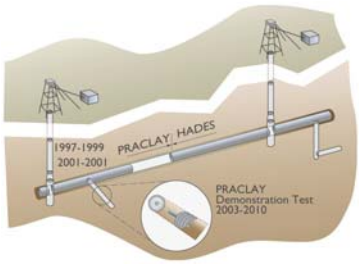
HADES (High Activity Disposal Experimental Site) underground research laboratory at Mol constructed to investigate Boom Clay.

HADES URL at Mol



Summary of main research items and processes associated with HADES URL

HADES URL / PARCLAY Project



A second shaft at the end of 1999 provided for a gallery to extend beyond the HADES URL for the PRACLAY project, which is designed to provide for an investigation of the disturbed zone around an HLW disposal gallery that has been subjected to decompression and thermal loading. Results to date indicate that more time will be required to obtain the desired results, and the project plan is now being redefined.

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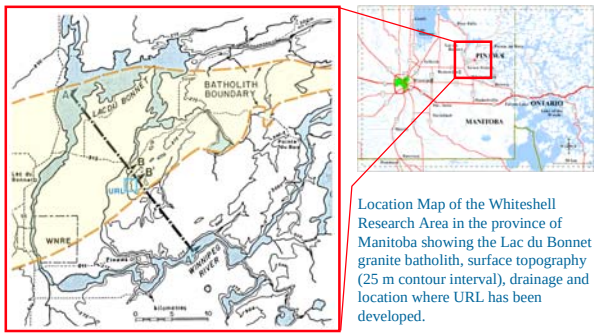
Whiteshell Research Area, Manitoba



Location Map of the Whiteshell Research Area in the province of Manitoba showing the Lac du Bonnet granite batholith, surface topography (25 m contour interval), drainage and location where URL has been developed.

Increasing use of URLs

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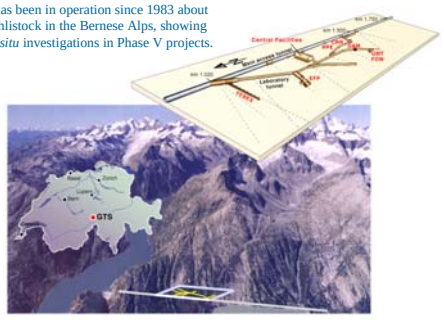
- 1980s Development of URL in Belgium
- 1980s Development of URL in Canada
- 1980s Development of two URLs in Switzerland

Phase V Projects at the Grimsel URL, Switzerland

Grimsel URL, which has been in operation since 1983 about 450 m beneath the Juchlistock in the Bernese Alps, showing locations of current *in situ* investigations in Phase V projects.



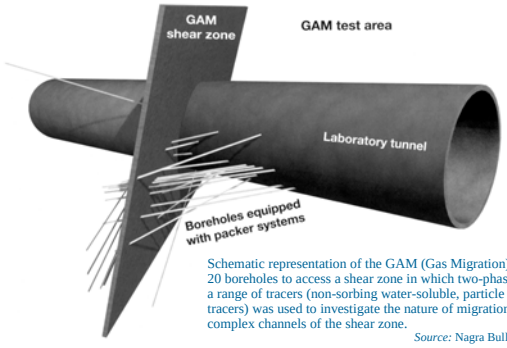
Source: Nagra Bulletin 34, 2002

Phase V (1997-2004) Projects and Participants at Grimsel URL

Experiment	Project Management, Partners	Description
CRR – Colloid and Radionuclide Retardation Lab programme 1997-1999 Field tests 2000-2002	**Nagra**, BMWI, FZK/INE, Enresa, JNC, US-DOE/CAO, SNL, Andra	Acquisition of data on the influence of colloids on radionuclide transport, supported by an extensive lab programme.
CTN – Conclusions on the Tunnel Near-Field 1998-1999	**Nagra**, BMWI, GRS, BGR, ERL/ITRI	Synthesis of aspects of the field investigations that are important for safety analysis.
EFP – Effective Parameters 1998-2002	**BMWI**, BGR, GRS, Nagra, ERL/ITRI	Development of methods for characterising fractured rock areas of representative size.
FEBEX – Full-scale Engineered Barrier Experiment FEBEX I: 1995-1999 FEBEX II: 2000-2004	**Enresa**, EC with 23 European partner organisations, Nagra	Testing the emplacement concept for HLW on a 1:1 scale (horizontal tunnel emplacement), understanding coupled thermo-hydraulic-mechanical-chemical processes. Optimisation of the EBS. Long-term monitoring, testing geochemical models, retrievability, improvement of codes.
FOM – Fibre-Optic Sensing Systems Operational Safety Monitoring 2001-2003	**BMWI**, DBE TEC, I. D. FOS, Nagra	Development and testing of fibre-optic systems as an alternative to conventional sensors.
GAM – Gas Migration in Shear Zones 1997-2002	**Nagra**, Enresa, US-DOE/CAO, SNL, Andra	Development of conceptual models for water/gas migration in heterogeneous shear zones. Development of the background for extrapolating flow and transport properties from the dm- to the m-scale.
GMT – Gas Migration Test in the EBS and Geosphere 1997-2004	**RWMC**, Nagra, Obayashi, Andra, BGR, GRS, Enresa (UPC)	Investigation of the behaviour of the engineered barriers (silo concept) in terms of gas transport. Optimisation of the EBS.
HPF – Hyperalkaline Plume in Fractured Rock 1997-2003	**Nagra**, JNC, SKB, US-DOE/CAO, SNL, Andra	Investigation of the effect of high-pH cement waters on radionuclide retention in natural systems.

Source: Nagra Bulletin 34, 2002

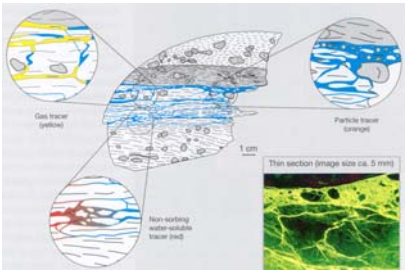
Gas Migration Test in Shear Zone



Schematic representation of the GAM (Gas Migration) test using 20 boreholes to access a shear zone in which two-phase flow with a range of tracers (non-sorbing water-soluble, particle tracers, gas tracers) was used to investigate the nature of migration in the complex channels of the shear zone.

Source: Nagra Bulletin 34, 2002

GAM Shear Zone

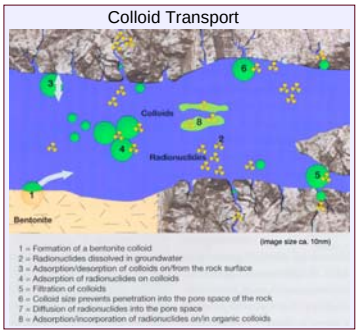


Structure of the GAM shear zone and migration of different tracers (schematic). Note the open channels. The thin section impregnated with resin shows the complex structure of the shear zone.

Source: Nagra Bulletin 34, 2002

Colloid and Radionuclide Retardation Test

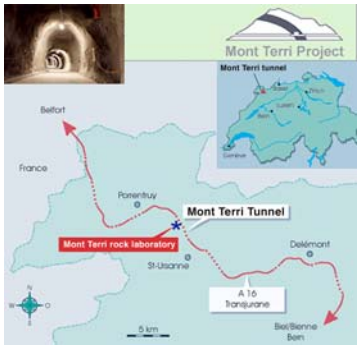
Colloid Transport



- Schematic representation of the CRR (Colloid and Radionuclide Retardation) test showing how colloids present in groundwater can influence the migration of radionuclides.
- Colloids in groundwater range in size from one nanometer to one micrometer, but they can also be formed due to the presence of the repository installations.
- Depending on their properties (e.g. size, charge), colloids can have the effect of either accelerating of delaying the transport of radionuclides."

Source: Nagra Bulletin 34, 2002

Mont Terri Project, Switzerland

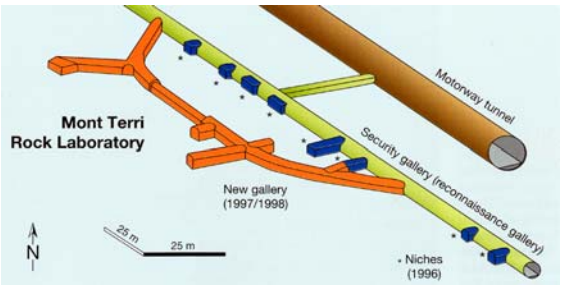


Map of Switzerland and the northwestern part of the country showing location of the Mont Terri URL that has been constructed in an underground offset from the Mont Terri motorway tunnel owned by the République et Canton du Jura with project direction by FOWG (Federal Office for Water and Geology).

Initial investigation of the site started in 1996 with excavation of 8 niches along the security gallery with funding provided by Nagra and 10 project partners in Switzerland, Belgium, France, Germany, Japan and Spain.

Source: Nagra Bulletin 34, 2002

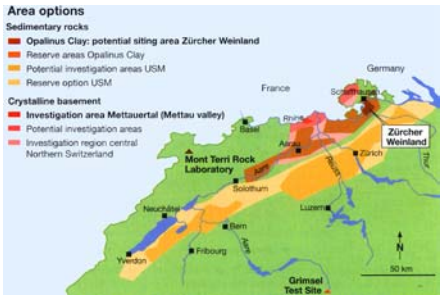
Tunnels and Niches in Mont Terri



Layout of tunnels and niches in the Mont Terri URL, that have been used to carry out a large number of experiments on the Opalinus Clay concerned with: its hydrochemistry, parameters of diffusion, effects of excavation on disturbed zone, and self-sealing behavior.

Source: Nagra Bulletin 34, 2002

Siting Area for Opalinus Clay in Zürcher Weinland



Source: Nagra Bulletin 35, 2004

Geological Profiles Through Zürcher Weinland

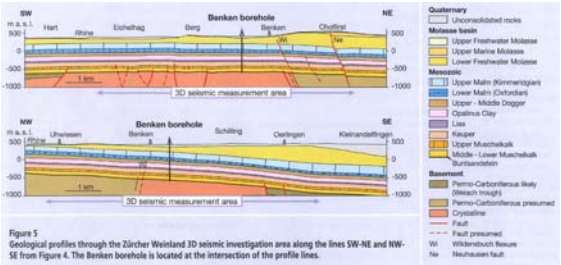


Figure 5
Geological profiles through the Zürcher Weinland 3D seismic investigation area along the lines SW-NE and NW-SE from Figure 4. The Benken borehole is located at the intersection of the profile lines.

Source: Nagra Bulletin 35, 2004

Hydraulic Conductivities and Heads in Benken Borehole

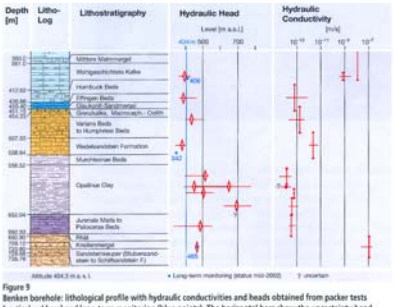
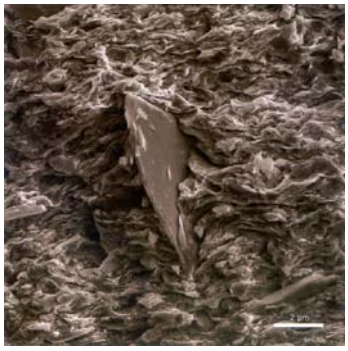


Figure 9
Benken borehole: lithological profile with hydraulic conductivities and heads obtained from packer tests (vertical red bars) and long-term monitoring (blue points). The horizontal bars show the uncertainty band-widths.

Source: Nagra Bulletin 35, 2004

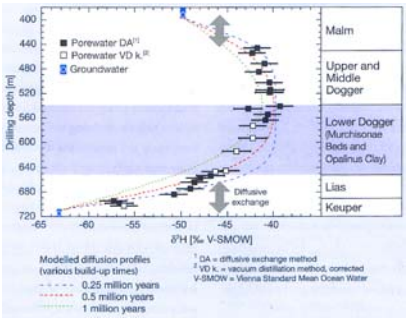
Opalinus Clay under Scanning Electron Microscope



The sample consists of clay minerals which have associated to form sheet-like aggregates.
In the center is a feldspar mineral.

Source:
Nagra Bulletin 35, 2004

Diffusion Profile of Deuterium in Benken Borehole



Measured data for deuterium (δ^2H) in groundwater and porewaters from the Benken borehole obtained using a range of methods. The arcuate distribution can be explained only by diffusive exchange (arrows) between groundwater and porewaters and excludes substantial vertical advective water flow. Model calculations (dashed lines) show that it has taken around 0.5 million years for the observed deuterium distribution to be established.

Source:
Nagra Bulletin 35, 2004

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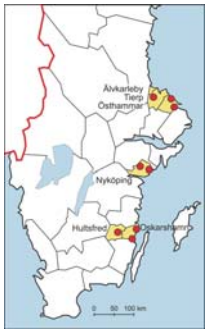
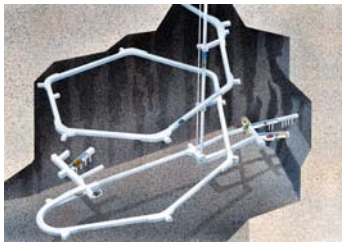
- 1980s Development of URL in Canada
- 1980s Development of two URLs in Switzerland
- 1980s Development of second URL in Sweden at Äspö

SKB Feasibility Study Sites



For almost 30 years, SKB (Swedish Nuclear Fuel and Waste Management Co.) has been working on their concept for a deep geologic repository that involves encapsulating HLW in copper canisters with cast iron inserts, imbedding each canister vertically, and surrounding them with bentonite clay at a depth of about 500 m in bedrock. SKB has also been carrying out feasibility studies at the eight sites shown here from which they selected three within the municipalities of Tierp, Östhammar, and Oskarshamn to determine if they would permit site investigations. The relevant authorities in Östhammar and Oskarshamn agreed to such work, which was initiated in the spring of 2002, and will continue for 5 to 6 years.

Äspö Hard Rock Laboratory



In preparing for the siting and construction of a deep repository, SKB has built the Äspö Hard Rock Laboratory (HRL) on the island of Äspö outside Oskarshamn. The HRL is 3600 m in length going down in a spiral to a depth of 450 m.

One of the first steps in using the HRL was to develop a procedure for emplacing the copper canisters in the repository tunnel floor. This required the development of a special boring machine that could construct a borehole 175 cm in diameter and 8 m deep and operate in tunnels with a roof height of only 5 m.

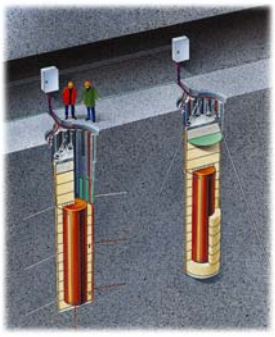
Copper Canisters

A special procedure for welding and fabrication has been developed to assemble a copper canister with a cast iron insert. The assembly is nearly 5 m long and weighs between 25 and 27 tons when filled with spent fuel.

SKB Radiation-shielded Deposition Machine

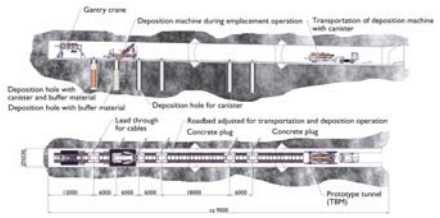
SKB has developed a prototype of a remote-controlled and radiation-shielded deposition machine to manipulate the heavy copper canisters in a tunnel with a roof height of only 5 m.

Layout of Retrieval Test



The repository is designed in such a way that it is possible to retrieve deposited canisters, and KBS is now carrying out a retrieval test to demonstrate that canisters can be freed from water-saturated bentonite under realistic conditions. The schematic layout shows a full-sized canister in a deposition hole surrounded with bentonite, which may take 3-5 years to become saturated.

Prototype Investigation of KBS-3 Repository



KBS is now testing a prototype of what they have designated as the KBS-3 design for a repository. The purpose is to simulate the integrated function of the repository components and to provide a full-scale reference for comparison with models and assumptions. The test area consists of six deposition boreholes, and is divided into two sections: one inner section with four canisters (electrically heated) and one outer section with two canisters (electrically heated). All conditions in the KBS-3 repository, with respect to geometry, materials, and rock conditions, are identical to a real repository. The outer part of the prototype repository will be excavated after 5 years, while the monitoring of the inner part will continue for another 5 to 10 years.

Increasing use of URLs 2001

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- 1980s Development of URL in Canada
- 1980s Development of two URLs in Switzerland
- 1980s Development of second URL in Sweden at Äspö
- 1996, 6 countries: Belgium, Canada, Japan (2), Sweden, Switzerland (2), USA
- 2001, 11 countries: Belgium, Canada, France, Japan (2), Sweden, Switzerland (2), and USA with URLs in operation; France, China, Czech Republic, Poland, and Ukraine with URLs being designed.

International Collaboration in Selected European URLs

Country (organisation)	**Involvement in selected European rock laboratories** (as of mid 2002)			
	Äspö	Grimsel	Praclay (Hades)	Mont Terri
Belgium				
SCK•CEN (Studiecentrum voor Kernenergie • Centre d'Etude de l'Energie Nucléaire)			x	x
Czech Republic				
Rawra (Radioactive Waste Repository Authority)		x		
EU				
EC (European Commission)	x	x	x	x
Finland				
Posiva (Posiva Oy)	x			
France				
Andra (Agence nationale pour la gestion des déchets radioactifs)	x	x	x	x
IRSN (Institut de radioprotection et de sûreté nucléaire)				x
Germany				
BGR (Bundesanstalt für Geowissenschaften und Rohstoffe)	x	x		x
BMWi (Bundesministerium für Wirtschaft und Technologie)	x	x		
DBEtec (Deutsche Gesellschaft zum Bau und Betrieb von Endlagern für Abfallstoffe Technology)		x		
FZK/INE (Forschungszentrum Karlsruhe / Institut für Nukleare Entsorgung)	x	x		
GRS (Gesellschaft für Anlagen- und Reaktorsicherheit)	x	x		x
Japan				
Criepi (Central Research Institute of Electric Power Industry)	x			x
JNC (Japan Nuclear Cycle Development Institute)	x	x		x
Obayashi (Obayashi Corporation)		x		x
RWMC (Radioactive Waste Management Funding and Research Center)		x		

International Collaboration in Selected European URLs
(cont.)

Country (organisation)	Involvement in selected European rock laboratories (as of mid 2002)			
	Äspö	Grimsel	Praclay (Hades)	Mont Terri
Sweden				
SKB (Svensk Kärnbränslehantering)	x	x		
Switzerland				
BBW (Bundesamt für Bildung und Wissenschaft, Federal Office for Education and Science)		x		x
BWG/FOWG (Bundesamt für Wasser und Geologie / Federal Office for Water and Geology)				x
GNW (Genossenschaft für nukleare Entsorgung Wellenberg)		x		
Nagra (Nationale Genossenschaft für die Lagerung radioaktiver Abfälle, Swiss National Cooperative for the Disposal of Radioactive Waste)	x	x		x
Spain				
Enresa (Empresa Nacional de Residuos Radiactivos)	x	x	x	x
Taiwan				
ERL/ITRI (Energy and Resources Laboratories / Industrial Technology Research Institute)		x		
United Kingdom				
Nirex (United Kingdom Nuclear Industry Radioactive Waste Executive)	x			
USA				
SNL (Sandia National Laboratories)	x	x		
US-DOE (United States Department of Energy)	x	x		

Source: Nagra Bulletin 34, 2002

Problems with Public Acceptance of Nuclear Waste Projects

In United Kingdom, Nirex was refused permission in 1997 to construct a URL at their Sellafield project, which led to the termination and abandonment of the project. In a review of the project by the office of the Secretary of State for the Environment, it was noted that the poor design, layout, and arrangements for access to the proposed URL, together with adverse impacts on visual amenities, a protected species (badgers), and the natural beauty of the English Lake District were serious enough to warrant refusal. There were also concerns about scientific uncertainties and technical deficiencies.

Problems with Public Acceptance of Nuclear Waste Projects

In 1993, an extensive site-selection procedure resulted in the nomination of Wellenberg in Central Switzerland as the preferred location for an LILW repository. The principle of using Wellenberg as a repository site was accepted in public referenda in the local community, but in 1995 was blocked by a narrow margin at the cantonal level.

Between 1996 and 2001, Wellenberg was evaluated again and a modified disposal concept to proceed with an exploratory drift received the necessary concession from the local government in September 2001.

Despite many of their requirements being fulfilled, the 1995 opponents decided to fight the concession with every resource at their disposal. Emotions ran extremely high in the weeks leading up to the cantonal vote in September 2002, with the result that a higher vote against the project than was obtained in 1995 was recorded. Wellenberg has now been officially abandoned, and at present, there are no alternative sites.

Radioactive Waste Disposal in Finland

The Finns have developed a successful method of handling this problem. When the first fieldwork for a HLW repository was about to begin, over 15 years ago, Posiva set up a cooperation group with the residents of each community where investigations were to be undertaken. They started with four different sites, and they established four separate cooperation groups. Several meetings with each group, including field trips, were arranged annually, and at the end of each year, a written report was given to each group that summarized all aspects of plans and results.

Radioactive Waste Disposal in Finland (cont.)

Before any significant commitment to a nuclear facility is made, Finnish law requires the passage of a Decision-in-Principle (DiP) by the government, which must include municipal approval. When all fieldwork at the 4 sites was completed, the final selection was based on the outcome of an environmental impact assessment carried out in 1997-1999. The final selection was a site at Olkiluoto in the municipality of Eurojoki, which had rendered a strong vote of approval for the proposed site. In December 2000, the Finnish government approved an application for the DiP that had been made, and on May 18, 2001, Parliament ratified the decision. Finland is the first country in Europe to obtain this kind of governmental approval for an HLW repository site.

Conclusions

Investigations on clay beds have revealed a formation with some unusual parameters, for isolating radioactive waste over very long periods of time.

One of the most important developments is the recognition that a URL provides an excellent facility for investigating and characterizing the parameters of a rock mass in the underground.

Once developed, a URL provides a convenient facility for two or more organizations to conduct joint investigations more economically than would otherwise be possible.

A very large number of cooperative projects have developed in Europe to take advantage of the opportunities provided by such joint ventures.

The role of the public, as a stakeholder in radioactive waste disposal, has not always been fully appreciated and must be given careful attention.

Appendix

The following Table 1.1 is from the Third Worldwide Review and summarizes the broad range of activities on nuclear waste isolation in 32 countries as of 2001.

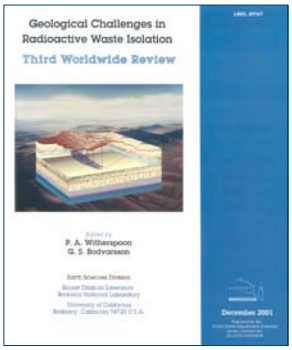

Table 1.1. Developments in radioactive waste isolation from 2001 *Third Worldwide Review* TBD—To be determined

Country	Lead Organization	Potential Sites	Prospective Rock Types	Status of Site Characterization	Prospective Design/Engineered Barrier	Near-Term Plans
Argentina	Comisión Nacional de Energía Atómica (CNEA)	TBD	Clay, evaporites, volcaniclastic, granite	Seven provinces chosen for site-selection purposes	TBD	Data being organized in GIS. Fracture mapping of satellite images is under way.
Armenia	Institute of Geological Sciences of the National Academy of Sciences	Somkheto-Karabakh, Central folded zones	Volcanic, gypsum, salt and clay, granite	Geologic and geophysical investigations	TBD	Complete geological, geophysical, volcanological, and seismotectonic investigations
Belarus	Institute of Geological Sciences	Polesye area, Gomel region	Granite, salt, clays	Geologic and geophysical investigations of region, numerical models of nuclide migration developed	Originally near-surface repositories; trench-type burial in future	Choose burial grounds with natural barriers, install barriers where needed, provide monitor and testing equipment
Belgium	SCK·CEN	TBD—Investigating Boom and Ieper Clay Formations	Clay	URL used 25 yrs for Boom Clay research, now studying effects of waste heat on safety and feasibility of clay	HLW in stainless steel over-pack with bentonite backfill and concrete liner	EURIDICE Consortium managing URL research including PRACLAY project on effects of waste heat on clay
Bulgaria	Geological Institute of Bulgarian Academy of Sciences	TBD—Loess near Kozloduy NPP (LILW), marl at Sumer and granite in Sakar pluton (HLW)	Loess for LILW, clayey marls and granite for HLW	Site-selection methodology developed, funding needed for specific investigations.	LILW pre-stressed concrete cubes at NPP; HLW in deep repository	Need waste-management regulatory body and funding for geological surveys and specific investigations
Canada	Ontario Power Generation (OPG)		Granitic	Since 1978, URL and other facilities used in site characterization studies and technology development.	2 designs: copper containers with waste in boreholes or drifts. Buffers and backfill seal off containers and rooms.	Develop waste-management organization to work with all stakeholders to develop approach that is socially, environmentally, and financially acceptable
China	Beijing Research Institute of Uranium Geology (BRIUG), China National Nuclear Corporation (CNNC)	Jiuqing Block in Beishan region of Gansu Province, NW China	Monzonitic granite	Beishan region selected from geological and geo-physical investigations; 2 boreholes drilled and cored	TBD	Comprehensive laboratory studies on core samples, investigate two other blocks in the next five years, and plan to start URL construction by 2015.

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Croatia	Hazardous Waste Management Agency (APO)	Trgovska gora site in Banovina region	Clayey schist, clay, sandstone	Analysis based on existing data and reports. Mines from war prevent field investigations.	Steeltube waste containers inside near-surface concrete vaults	Detailed geological mapping, geophysical surveys, and borehole drilling to provide data for site characterization.
Czech Republic	Radioactive Waste Repository Authority (RAWRA)	Dukovany for ILW and LLW; TBD for HLW	Granite for HLW	Five areas selected for site characterization. Methods & techniques to be developed at Melechov Massiv.	Steel container; bentonite buffer and backfill	Two candidate sites selected by 2015 and final site by 2024. URL starts at site in 2025 and in operation by 2030.
Finland	Posiva Oy	Olkiluoto near NPP at Eurajoki, with existing repository for LILW and new repository site for HLW	Granite	Olkiluoto chosen from detailed site characterization, favorable EIA and small social impact. Eurajoki OK'd site and Parliament gave final approval 5/18/01.	Encapsulation in bedrock several hundred meters deep in metal canisters with buffer and backfill	Verify site suitability, define adequate repository space, characterize host rock for repository, safety assessment, and plan construction. Submit construction license application in 2010.
France	Agence Nationale pour la Gestion des Déchet Radioactifs (ANDRA)	Meuse/Haute-Marne and 15 potential sites in granite areas	Argillite at Meuse site and granitic batholiths	Sinking shaft at Meuse site for URL in clay, and designing series of key experiments. Participating in 5 granitic experiments in foreign URLs.	Investigating preliminary concepts for designs of disposal cells in clays using tunnels and caverns	Conduct research in URL at Meuse site to provide reliable data to answer key questions on performance assessment of repository in clay. Prepare feasibility report on granite site in 2006.
Germany	Federal Office for Radiation Protection (BfS)/Federal Institute for Geosciences and Natural Resources (BGR)	Gorleben salt dome, Konrad iron ore mine	Rock salt, hard rock sediment within clay barrier	Licensing procedure for Konrad finished in 1992 but not yet approved. Exploration at Gorleben stopped. New procedure for site selection expected in 2002.	Steel container; backfill material depending on waste type and host rock	Pursue concept of constructing one simple repository for all types of radwastes. Participating in R&D programs in Belgium, France, Spain, Sweden, Switzerland, and US.

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Hungary	Public Agency for Radioactive Waste Management (PURAM)	Üveghuta site for LILW , Bodx site for HLW	Granite at Üveghuta site, Bodx Claystone at Bodx site	At Üveghuta, site characterization and social impact programs peer reviewed and approved by IAEA. HLW to be stored at NPP for up to 50yrs pending policy decisions.	At Üveghuta site, waste drums and disposal containers to be emplaced in tunnels with clay in backfill material.	Site characterization and repository design at Üveghuta to continue, public outreach program to continue to establish long-term relationship between local communities and project management.
India	Bhabha Atomic Research Center	Sankara pluton in northwest Rajasthan	Granite	Geophysical surveys, geological and geochemical studies, hydrogeological/rock-mechanical testing carried out.	TBD	Favorable results over an area of a few thousand km² indicate need for additional, more detailed investigations.
Italy	National Agency for New Technology, Energy, and Environment (formerly ENEA)	Near-surface repository for LLW. Long-term storage for HLW at the same site.	TBD	Nuclear energy phased out after 1987. General site-selection process using GIS methodology, in three steps, is ongoing over entire country.	Repository with modules of reinforced concrete containers and steel boxes for LLW. Long-term storage of HLW in castor-type casks.	Third step in GIS methodology currently ongoing for 300 suitable areas identified in second step. Repository scheduled to begin operation in 2009.
Japan	For implementation, the Nuclear Waste Management Organization of Japan (NUMO); for R&D, Japan Nuclear Cycle Development Institute (JNC)	TBD	Crystalline or sedimentary rocks. URLs at Mizunami and Horonobe	Second progress report (H12) completed to demonstrate feasibility, safety, and reliability of disposal concept and to provide input for future siting and regulatory processes. Needed methodology being developed at Mizunami and Horonobe.	Vitrified waste in steel over-pack embedded in bentonite and emplaced either in tunnels or in vertical holes drilled from bottom of tunnels.	Keep stakeholders informed on all developments via data-base on JNC website, provide public with virtual repository to visualize underground system. NUMO will keep public advised of potential sites, details of planned repository and basis for final site selection. Work on new methodology continues at both URLs.

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Korea	Korea Hydro & Nuclear Power Co. (KHNP) for LILW; Korea Atomic Energy Research Institute (KAERI) for HLW	TBD	Andesite for LILW, Mesozoic plutonic rocks for HLW	Preliminary conceptual design and safety assessment for LILW repository in rock cavern and vault options completed. Plutonic rocks screened as primary host rock for HLW repository. Conducted radio-nuclide migration studies and developed performance assessment code.	Rock storage cavern and cement-grouted vault for LILW. Encapsulate HLW in corrosion-resistant containers in boreholes, with bentonite buffer, drilled in tunnels at depth of ~500 m.	Preliminary assessments of conceptual facilities for LILW provide firm foundation for site-specific assessment activities. Site-specific data required for next stage of LILW project. Next step for HLW repository is further development of repository concept using field data from in situ investigations at specific site(s).
Lithuania	Lithuanian Energy Institute	TBD for SNF and LILW. Existing solid LILW storage facilities at Ignalina NPP cannot be converted to repositories.	For SNF, clay, anhydrite, salt, and crystalline bedrock	Analysis is ongoing, based on existing data and reports	TBD for SNF. Reference design for near-surface LILW repository (concrete vaults)	For SNF, research to develop competence in performance assessment and to select disposal concept that can be adapted to different sites; development of site-selection methodology. For LILW, siting for near-surface repository
Netherlands	Ministry of Environment Steering Commission for Research (CORA)	Retrievable disposal site for HLW at Borssele NPP	Rock salt, clay	Analysis of long-term retrievable storage at surface and underground, in either salt or clay, for up to 300 yrs appears technically feasible	HLW consisner in individual cells in tunnel wall. Crushed salt used for buffer in salt; clay-bentonite in clay.	CORA recommends continuation of research program to further improve technical solutions and involve stakeholders in ethical and social aspects.

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Poland	National Atomic Energy Agency of Poland	Shale at Jarocin and salt domes at Damasławek, Kłodawa, and Łanięta	Triassic shale in SW Poland, salt domes in the Polish Lowland	First geological review led to selection of 44 sites of which four were chosen as promising: one in shale and three in salt domes.	TBD	Continue more detailed site-selection process, construct URL in one of the salt domes to investigate in situ argillaceous-salt conditions.
Romania	Institute of Nuclear Research	TBD	Salt	Long-term safety assessment for repository in hypothetical salt formation has been carried out.	TBD	As site characterization work is carried out and in situ data become available, more realistic safety assessment investigations will be made.
Russia	Minatom; All-Russia Designing and Research Institute of Production Engineering	Tomsk-7, Krasnoyarsk-26, Dimitrovgard, Mayak, Novaya Zemlya archipelago	Sand and sandstone for liquid wastes. Hard rock for solid wastes.	Liquid waste isolation has worked satisfactorily since 1963. Isolation of solidified waste in hard rock massifs, mined out areas, and permafrost now being investigated.	TBD	Disposal of liquid radioactive waste to be completed by 2015 and projects will be shut down. Solidified waste will be stored at surface while geological repositories are being researched and constructed, with operation after 2025.
Slovak Republic	Decom Slovakia	Tribec, Zior, Veporske vrchy, Sodicke vrchy in granitic rocks Carova vrchovina, Rimavska kotlina in sedimentary rocks	Granite, siltstones and clays	A revised program in development activities has been used to select 4 prospective granitic sites and 2 argillaceous sites. Selection of a host rock will not be made before 2005. Selection of candidate sites is expected around 2010.	Proposed disposal container with 7 WWER-440 SF assemblies to have outer wall of carbon-steel coated with nickel and inner wall of stainless steel. The inner cask would be an aluminum alloy.	Activities should lead to proposal for a first-reference disposal concept, a public-involvement program, information database, investigation of prospective sites, revision of siting criteria, performance assessment based on available data, and selection of materials for engineered barrier.
Slovenia	Agency for Radioactive Waste (ARAO)	TBD	Unconsolidated sediments, hard clay, granite	Areas suitable for LILW repository selected' preliminary geological assessment done	Geological conditions suitable for disposal in surface and underground	Site suitability investigations to be carried out, subject to public response. Plan to select site by 2005.

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South Africa	South Africa Nuclear Energy Corporation (NECSA)	Vaalputs National Radioactive Waste Disposal Facility	Clay, granite	Drilling in Vaalputs area (1996) found excellent granitic rock, but work was stopped—new national policy now being drafted.	TBD	If geologic disposal is to be part of national policy, all stakeholders are to be involved. International cooperation is essential, various options (including regional repository) to be included.
Spain	Empresa Nacional de Residuos Radioactivos (ENRESA)	TBD	Clay, granite	Detailed analyses of several potential repository sites have been made. Large database from this work now being managed on EIS, which will be up-dated until 2010.	Carbon-steel canisters embedded horizontally in bentonite buffer spaced 2 m apart in drifts	Develop geologic disposal R&D program with models for site characterization, flow and transport scenarios and performance assessment. Develop generic design for repository in clay or granite; study natural analogs; establish safety criteria.
Sweden	Swedish Nuclear Fuel and Waste Management Co. (SKB)	Oskarshamn in SE Sweden, Tierp and Östhammar in northern Uppland	Granite URL in granite at Aspö	Feasibility studies led to 3 potentially suitable sites for deep repository, approval for site investigations needed from local municipalities. URL at Aspö conducting R&D on methodology needed for deep repository.	Waste in copper canister with cast inserts embedded in bentonite in vertical holes in tunnel filled with bentonite and crushed rock at depth of ~500 m.	With local approval, site investigations to start in 2002. Much work on canister fabrication underway at Canister Laboratory in Oskarshamn. Research on repository technology now concerned with a retrieval test, backfill and plug test, and prototype repository.
Switzerland	National Cooperative for the Disposal of Radioactive Waste (NAGRA); Genossenshaft für nukleare Entsorgung Wellenberg (GNW)	Wellenberg for LILW, HLW/SF/TRU siting studies in Northern Switzerland	Marl at Wellenberg clay, granitic basement in N. Switz.; URLs at PN, Terri in Opalinus Clay and at Grimsel in granite/ granodiorite	Wellenberg LILW site accepted at local level but blocked at cantonal level by narrow margin. Opalinus Clay and granitic basement in Northern Switzerland extensively investigated, including 3D seismics and deep boreholes.	SF/HLW in steel canisters embedded horizontally in tunnels with bentonite backfill. LILW / TRU in concrete emplacement containers in caverns backfilled with cementitious grout	Second referendum at Wellenberg in 2002 may permit exploration tunnel to gather data to support application for construction license. Siting feasibility project for HLW/SF/TRU focused on the Opalinus Clay of the Zuercher Weinland to be produced in 2002

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Taiwan	Fuel Cycle and Materials Administration (AEC)	Little Chiu Yu at Wu-Chiu Hsiang for LLRW. SF currently stored in on-site pools at NPPs.	Granite, shale, mudstone	EIS for Little Chiu Yu under review with Taiwan EPA. Approval of feasibility and safety analysis reports plus EIS needed for final approval of site.	TBD	SF disposal under study in project spanning 40 years (1991–2031). Expect SF disposal site identified by 2016 and repository commissioned by 2032. On-site dry storage to supplement on-site pool storage.
Ukraine	Institute of Geological Sciences	Korosten pluton and Malokhov block in Ukrainian shield and salt domes in Dnieper-Donets depression	Granite, salt domes	Site selection and characterization methodologies defined, funding problems with economic restrictions	TBD	Complete R&D on site characterization (1999-2005), characterize selected site, develop URL, demonstrate site safety, obtain license and decision on construction (2005-2020).
United Kingdom	United Kingdom Nirex, Ltd	TBD	TBD	Request for permission to build a URL near Sellafield rejected by local council and decision supported by Secretary of State for the Environment. Work at Sellafield terminated.	TBD	Parliamentary review (1999) points to need for public acceptance of policy on waste management before problem can be settled. Citizen's Panel issues number of suggestions. Government issues proposal (2001) to develop, and implement, a waste-management program that inspires public support and confidence.
United States	United States Department of Energy	Yucca Mountain, Nevada	Volcanic tuff	Site selection and site characterization methodologies have been developed and applied in evaluating Yucca Mountain	Waste within two concentric cylinders (stainless steel inside corrosion-resistant nickel alloy) covered with drip shield and placed horizontally in drifts.	Quantitative assessments of long-term performance of repository for various features, events, and processes is ongoing. Performance-confirmation program established to monitor and confirm repository is behaving as expected. These preclosure-period activities may last up to 300 years.